

## Tephra record of volcanic activity in Klyuchevskoy Group of volcanoes during the Early Holocene

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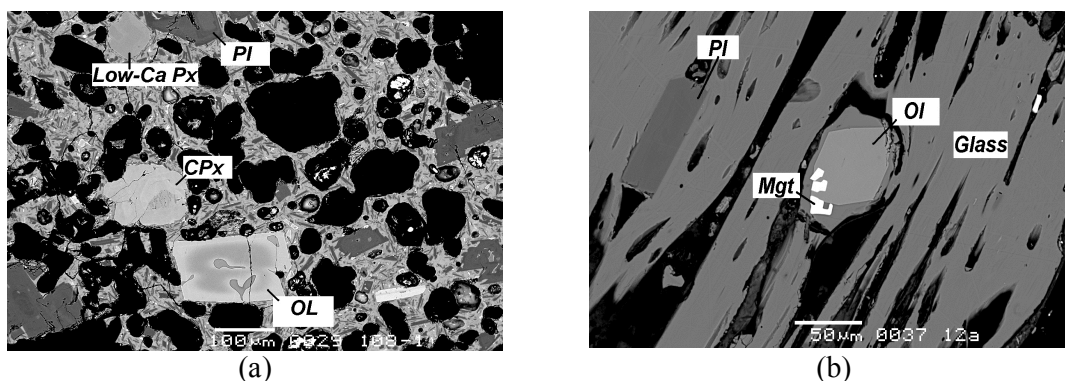
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The Klyuchevskoy Group is the largest cluster of active volcanoes in Kamchatka. The history of volcanism in the Klyuchevskoy Group of volcanoes is however not well known. The goal of this study was identification of volcanoes, which were active in the Klyuchevskoy Group during the Early Holocene, and petrologic character of their pyroclastic rocks.

The rocks studied here were collected from a 12-meter-thick tephra sequence on the northeastern foot of Klyuchevskoy volcano during KALMAR field expeditions in Kamchatka in 2007 and 2008. The section comprises a large number of variably grained cinder layers, which span a wide range of composition and were deposited during the entire Holocene. We investigated tephra samples collected from the lower 5 meters of this section, below a thick (0.5 m) layer of Klyuchevskoy cinders (so called “Upper cinders”) dated as around 6 ky <sup>14</sup>C and related to the beginning of intensive construction of the Klyuchevskoy volcanic cone [1]. Dating of rocks in the section was performed by interpolation of age data between recognized regional marker cinder layers of known age [1, 2]. The age of mafic layers was estimated to be between 6.8 and ~11.3 ky cal. BP. The accuracy of the age estimates is about ±150 cal. years.

On the basis of the age data, petrographic, mineralogical and geochemical data, three rock groups were identified, which were erupted during 6.8 - 9.9, 9.9 - 10.5, 10.5 -11.3 ky cal. BP, respectively.



**Figure 1.** BSE images of tephra samples. (a) Groups 1 and 3; (b) group 2.

The rocks of the 1st and 3rd groups (6.8 - 9.9 and 10.5 -11.3 ky cal. BP) have porphyritic textures, microlithic highly vesicular groundmass. *Ol*, *Cpx*, *Pig* and *Pl* present as phenocrysts and microliths (Fig. 1a). Magnetite (*Mgt*) occurs in some samples. Phenocrysts and microliths have similar compositions and exhibit normal or reverse zoning. Minerals with contrasting types of zoning coexist in some samples. The samples referred to this

geochemical group have compositions corresponding to middle-K high-alumina basalts and andesites [3] (Table 1). On the petrochemical diagram proposed by M. Peacock [4] these rocks fall at the boundary between calcic and calc-alkali series ( $\text{SiO}_2=61$  wt %) [5]. Typical values of  $\text{K}_2\text{O}/\text{TiO}_2$  in matrix glasses and melt inclusions are in the range 0.5-1.26. The compositions of these rocks closely resemble those of Klyuchevskoy and Kamen' volcanoes.

**Table 1.** Average major element compositions of groundmass glasses (wt %).

Rock group	$\text{SiO}_2$	$\text{TiO}_2$	$\text{Al}_2\text{O}_3$	$\text{FeO}$	$\text{MnO}$	$\text{MgO}$	$\text{CaO}$	$\text{Na}_2\text{O}$	$\text{K}_2\text{O}$	$\text{P}_2\text{O}_5$
1	$58.0 \pm 1.7$	$1.8 \pm 0.2$	$14.2 \pm 0.4$	$9.7 \pm 0.9$	$0.2 \pm 0.03$	$3.4 \pm 0.7$	$6.6 \pm 0.8$	$3.6 \pm 0.3$	$1.7 \pm 0.4$	$0.29 \pm 0.07$
2	$60.1 \pm 1.1$	$1.5 \pm 0.1$	$15.1 \pm 0.6$	$7.5 \pm 0.3$	$0.1 \pm 0.02$	$2.2 \pm 0.3$	$5.0 \pm 0.5$	$3.7 \pm 0.2$	$3.1 \pm 0.3$	$0.69 \pm 0.09$
3	$57.5 \pm 1.2$	$1.9 \pm 0.3$	$13.9 \pm 0.4$	$10.1 \pm 0.7$	$0.2 \pm 0.02$	$3.4 \pm 0.6$	$6.5 \pm 0.7$	$3.7 \pm 0.3$	$1.7 \pm 0.3$	$0.28 \pm 0.06$

The rocks of the 2nd group (9.9 - 10.5 ky cal. BP) are distinguished by highly porphyric texture and glassy matrix. Rock fragments are often tubular, elongated (Fig. 1b). Phenocrysts of Pl and Px are rare. Pl crystals are typically tabular and significantly larger (up to 1 sm) than in the rocks of the first group. Microliths are represented by rare *Ol*, *Pl*, *Cpx*, *Pig*, *Mgt* and *Ap*. Except *Pl*, microliths have more primitive compositions compared to phenocrysts or subphenocrysts. The minerals exhibit predominantly reverse zoning. The rocks of this group have high-K trachyandesitic composition (Table 1). According to the Peacock index ( $\text{SiO}_2=58.5$  wt %), the rocks belong to calc-alkaline series [5]. They have approximately two times higher concentrations of  $\text{K}_2\text{O}$  and  $\text{P}_2\text{O}_5$  (Fig. 2) and similar content of the major elements compared to the rocks of the younger group. The  $\text{K}_2\text{O}/\text{TiO}_2$  ratio in matrix glasses and melt inclusions is typically in the range of 1.26-3.52. Close analogs of these rocks are high-K andesites and basaltic andesites of Ushkovsky volcano [6].

In result of the study of Early Holocene pyroclastic deposits at the foot of Klyuchevskoy volcano, we identified rocks of two major types. Middle-K tephras erupted 6.8 - 9.9 and 10.5 -11.3 ky cal. BP are compositionally similar to the rocks of Klyuchevskoy volcano. High-K tephras formed 9.9-10.5 ky cal. BP are likely eruptive products of Ushkovsky volcano. Our new data suggest that activity of Klyuchevskoy volcano could have been started ~up to 5 ky years earlier than it was supposed in previous works.

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